Reconnaissance surveys of contaminants potentially affecting Green Bay and Gravel Island National Wildlife Refuges

Tara B. Dale
Kenneth L. Stromborg

U.S. Fish and Wildlife Service

Green Bay Ecological Services Field Office
1015 Challenger Court
Green Bay, WI 54311

DECEMBER 1993

ACKNOWLEDGEMENTS

Major contributions in the field were provided by D.S. Amundson, B.R. Freske, J.H. Braastad, W.H. Karasov, J.M. Larson, L. Sileo, and P.J. Warpinski. Special thanks to A. Ross and E. Hammett for access to privately owned islands. The manuscript was reviewed by G.H. Heinz and T. Bartish.

TABLE OF CONTENTS

List of Tables iv

List of Figures vi

List of Appendices vi

Abstract vii

Introduction 1

Objectives 2

Study Area 2

Methods 4

Results 6

Discussion 9

Conclusions and Recommendations 11

References 12

List of Tables

Table 1. Chemical concentrations (ppm, wet-weight) in soil/guano collected from islands in Green Bay and Lake Michigan during 1987 15

Table 2. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Kidney Island, Green Bay during 1987 16

Table 3. Chemical concentrations (ppm, wet-weight) in miscellaneous biota collected from islands in Green Bay and Lake Michigan during 1987 17

Table 4. Metal concentrations (ppm, dry-weight) in soil/guano collected from islands in Green Bay and Lake Michigan during 1987 18

Table 5. Metal concentrations (ppm, dry-weight) in avian eggs collected from Kidney Island, Green Bay during 1987 19

Table 6. Metal concentrations (ppm, dry-weight) in miscellaneous biota collected from islands in Green Bay and Lake Michigan during 1987 19

Table 7. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Cat Island, Green Bay during 1988 20

Table 8. Chemical concentrations (ppm, wet-weight) in biota collected from Hat Island, Green Bay during 1988 21

Table 9. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Jack Island, Green Bay during 1988 22

Table 10. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Spider Island, Lake Michigan during 1988 23

Table 11. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Gravel Island, Lake Michigan during 1988 24

Table 12. Chemical concentrations (ppm, wet-weight) in biota collected from Pilot Island, Lake Michigan during 1988 25

Table 13. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Hog Island, Lake Michigan during 1988....... 26

Table 14. Chemical concentrations (ppm, wet-weight) in cormorant eggs collected from Fish Island, Lake Michigan during 1988..27

Table 15. Body burdens of PCBs (mg) in adult male double-crested cormorants collected from Cat Island, Green Bay during 1988..28

Table 16. Chemical concentrations (ppm, wet-weight) in adult double-crested cormorants collected from Cat Island, Green Bay during 1988... 29

Table 17. Chemical concentrations (ppm, wet-weight) in gut contents of double-crested cormorants collected from Cat Island, Green Bay during 1988................................ 30

Table 18. Chemical concentrations (ppm wet- and lipid-weight) in carcasses and livers of adult male double-crested cormorants collected from Cat Island, Green Bay during 1988..31

Table 19. Chemical concentrations (ppm, lipid-weight) in carcasses and yolk/whole eggs of laying double-crested cormorants collected from Cat Island, Green Bay during 1988............ 32

Table 20. Chemical concentrations (ppm, wet-weight) in double-crested cormorants eggs collected from individual nests on Spider Island, Lake Michigan during 1988.................. 33

Table 21. Estimated variance components for 8 whole clutches of cormorant eggs..34

List of Figures

Figure 1. Map of northeastern Wisconsin showing nine islands in Green Bay and Lake Michigan where biota samples were collected during 1987 and 1988.............................. 3

List of Appendices

Appendix I. Estimated detection limits (ppm, dry-weight) for metals in analyses of soil/guano, avian eggs, and avian carcasses collected from islands in Green Bay and Lake Michigan during 1987.............................. 35

ABSTRACT

Biota samples were collected from several islands in Green Bay and Lake Michigan during 1987-1988 and were analyzed for various organochlorines and metals. PCBs and DDE were detected at all locations, and concentrations were higher in fish-eating species such as herring gulls (*Larus argentatus*) and double-crested cormorants (*Phalacrocorax auritus*) than in waterfowl species. In addition, oxychlordane, hexachlorobenzene (HCB), beta-BHC, delta-BHC, alpha-chlordane, gamma-chlordane, trans-nonachlor, cis-nonachlor, heptachlor epoxide, DDD, DDT, dieldrin, and mirex were found in various samples. Although remaining relatively high, PCB, DDE, and dieldrin levels have decreased in some biota during the past ten years. Local sources of PCBs were important in cormorants, as levels in adult males increased temporally from 43.0 ppm during pre-nesting stage to 84.8 ppm during incubating stage. In cormorants, differences in PCB and DDE variability between clutches compared to variability within clutches indicates that single eggs can be used to characterize the contaminant burdens of entire clutches.

INTRODUCTION

The U.S. Fish and Wildlife Service (Service) is responsible for managing three wilderness areas in the northern Lake Michigan waters of Wisconsin. These islands were "reserved and set apart...as a preserve and breeding ground for native birds" by Executive Orders in 1912 and 1913 (Taft 1912, Taft 1913) and ultimately were designated as National Wildlife Refuges. These, and similar islands in Green Bay itself, support a variety of trust species, including colonial nesting birds such as the double-crested cormorant (*Phalacrocorax auritus*) and herring gull (*Larus argentatus*), as well as a variety of waterfowl.

Previous studies by the Patuxent Wildlife Research Center established that the biota of these islands were heavily contaminated with various organochlorines, such as DDE, dieldrin, and polychlorinated biphenyls (PCBs) (Haseltine *et al.* 1981, Heinz *et al.* 1983). These studies were prompted by the results of White and Cromartie's (1977) national comparative survey of organochlorine contamination of red-breasted merganser (*Mergus serrator*) eggs which indicated that mergansers in this area of Lake Michigan were the most highly contaminated in the eastern United States. Piscivorous species such as mergansers and cormorants are useful indicators of contaminant levels in the ecosystem because fish tend to bioaccumulate persistent chemicals like organochlorines. Organochlorine contamination is high in Green Bay, as well as in the entire Lake Michigan system (Evans 1988). Because clean-up efforts for the Lake Michigan ecosystem are at a threshold for making major progress in ecosystem rehabilitation, it is important to track progress toward the ultimate goal of restoration.

A series of investigations was undertaken in the Green Bay area during 1987-1988 to measure contaminant concentrations in trust resources, including those on Service refuge islands and other islands of similar size and ecological character. Residue data were collected from a variety of substrates and locations. More extensive data were gathered on double-crested cormorants, including time-related contaminant uptake in adults and contaminant variation in whole clutches. These data will provide valuable background information about the role of contaminants in the welfare of Service trust species in this area and serve as a reference point for tracking clean-up efforts. In addition, these data will assist in interpreting the results of parallel efforts at elucidating causal relationships between contaminants and biotic effects (Larson 1991, Tillitt *et al.* 1992, Heinz *et al.* in prep.) that may be used to support claims for damages to natural resources on Service lands.

OBJECTIVES

1) To provide information on the distribution of contaminants within selected environmental compartments and to identify future sampling subjects. The survey was designed to determine whether or not the declining levels of contaminants in the Lake Michigan/Green Bay physical environment and food web have been reflected in decreases in contaminant burdens in biota, thereby providing a historical perspective to prior studies of contaminants in the area avifauna.

2) To determine contaminant concentrations in whole bodies and livers of adult cormorants during successive stages of nesting in order to evaluate the importance of local sources of contaminants.

3) To evaluate within and between clutch variation in contaminant levels in cormorant eggs, in order to determine whether a single randomly selected egg from a clutch can be used to characterize the contaminant burden of the entire clutch. This information was needed to plan future studies related to impairment of reproduction.

STUDY AREA

Samples were collected from four islands in Green Bay and five islands in Lake Michigan (Figure 1). Green Bay islands included Kidney Island, a confined disposal facility for contaminated dredge spoils (0.8 km east of the mouth of the Fox River, Green Bay, Brown Co., WI), Cat Island (2.1 km north of Green Bay, Brown Co., WI), Hat Island (8.4 km northwest of Egg Harbor, Door Co., WI), and Jack Island (6.8 km northwest of Fish Creek, Door Co., WI). Lake Michigan islands (all located in Door Co., WI) included Spider Island (9.2 km southeast of Ellison Bay), Gravel Island (9.1 km east of Ellison Bay), Pilot Island (8.5 km east of Gill's Rock), Hog Island (16.5 km northeast of Gill's Rock) and Fish Island (24.8 km northeast of Gill's Rock). Spider, Gravel, and Hog Islands are part of the National Wildlife Refuge system and are designated wilderness areas.

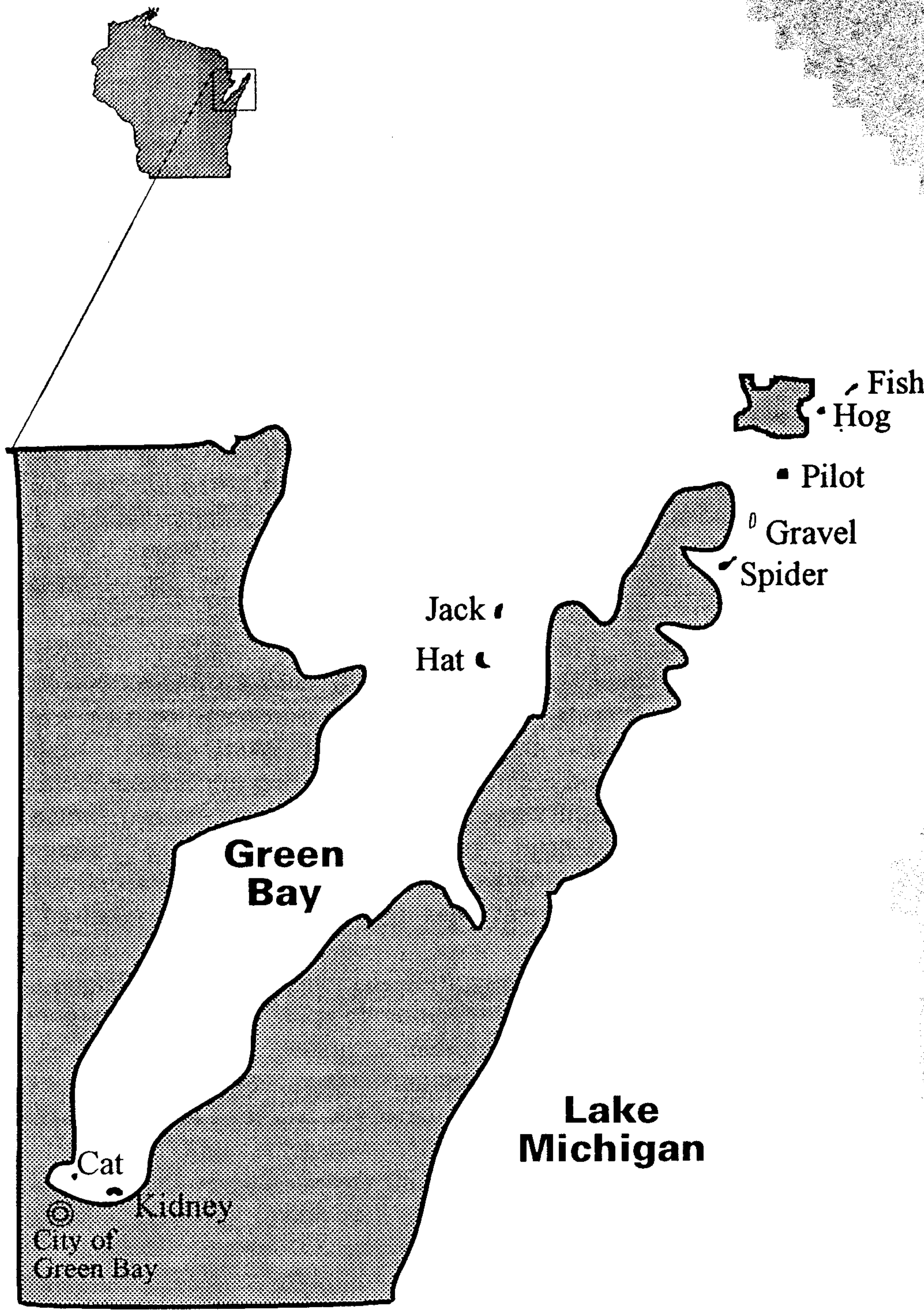

Figure 1. Map of northeastern Wisconsin showing nine islands in Green Bay and Lake Michigan where biota samples were collected during 1987 and 1988.

METHODS

Sample collection

Survey, 1987

Samples from several different matrices were collected. On Hat, Jack, Spider, and Gravel Islands, composite soil/cormorant guano samples from beneath trees containing active cormorant nests were placed in chemically clean jars using an acetone-washed metal trowel. These samples were frozen until analyzed. On Kidney Island, Forster's tern (*Sterna forsteri*) and common tern (*Sterna hirundo*) eggs were collected early in incubation and refrigerated until the contents were transferred to chemically clean jars. One shell-less herring gull egg was found and collected from Hat Island. Samples were stored frozen until analyzed. Mallard (*Anas platyrhynchos*), northern pintail (*Anas acuta*), gadwall (*Anas strepera*), black-crowned night heron (*Nycticorax nycticorax*), and cormorant carcasses were salvaged when encountered on Kidney, Cat, and Spider Islands, wrapped in aluminum foil, and stored frozen until analyzed.

Survey, 1988

More species and a greater geographic area were sampled than in 1987. Biota samples were collected from Green Bay (Cat, Hat, and Jack Islands) and Lake Michigan (Spider, Gravel, Pilot, Hog, and Fish Islands). Samples included cormorant, herring gull, black-crowned night heron, mallard, gadwall, red-breasted merganser, and Canada goose (*Branta canadensis*) eggs, and garter snake (*Thamnophis sirtalis*) carcasses. Eggs were handled as before; the snakes were collected by hand, placed in chemically clean jars, and euthanized by freezing. All samples were kept frozen until analyzed.

Contaminant uptake by adult cormorants during nesting

During early spring 1988, adult cormorants were shot at intervals from the time they arrived on the breeding grounds on Cat Island through egg-laying and early stages of incubation. In the laboratory, the birds were necropsied and a subsample of each liver and any large, active yolks were placed in chemically clean jars. Gut contents were removed and wrapped in aluminum foil, and the remainder of each carcass was wrapped separately in aluminum foil. All samples were kept frozen until analyzed.

Estimation of contaminant variation in whole clutches

During May 1988, entire clutches were removed from nests on Spider Island and eggs were individually archived and frozen.

Laboratory methods

Survey, 1987

Homogenization and metals analyses were performed by Environmental Trace Substances Research Center in Columbia, Missouri. Carcasses were plucked, and feet, beak, and gut contents were removed and discarded. Mercury concentrations were determined by cold vapor atomic absorption and arsenic concentrations were determined by graphite furnace atomic absorption. Other metal concentrations were determined by inductively coupled plasma with preconcentration. Metals are reported on a dry-weight basis. Detection limits for metals are given in the appendix.

Analyses for organochlorine compounds were performed by gas chromatography/mass spectrometry at Mississippi State University. Results are reported on a wet-weight basis, with % lipid reported for reference. The lower level of detection for tissue and soil was 0.01 ppm.

Survey, 1988

Chemical analyses were performed at Texas A&M University in College Station, Texas. Tissue samples were homogenized and the quantitative analyses were performed by Sephadex chromatography (CGC) with a flame ionization detector for aliphatic hydrocarbons, CGC with electron capture detector for pesticides and PCB's, and a mass spectrometer detector in the SIM mode for aromatic hydrocarbons. Results are reported on a wet-weight basis. Detection limits were 0.50 ppm for total PCBs and toxaphene and 0.05 ppm for the remaining chemicals.

Adult cormorant uptake and whole clutch variance

Samples were shipped to Mississippi State University for organochlorine analyses by capillary column, flame ionization gas chromatography and fluorescence HPLC in the adults and packed column, electron capture gas chromatography in the clutches. Results are presented as ppm, wet-weight. Detection limits were 0.05 ppm for total PCBs and toxaphene and 0.01 ppm for the remaining chemicals.

Statistical analyses

Chemical concentrations in eggs were corrected for moisture loss (Stickel *et al.* 1973), unless otherwise noted. In these cases, egg volume data were not available. Arithmetic means and standard deviations were calculated for all chemical and metal residues. When residues were not detected in an individual sample, one half the detection limit was the value used in calculating the mean. Two-sample *t*-tests were used to compare Forster's tern PCB residues in 1983 and 1988, incorporating a procedure to test for unequal variances (Snedecor and Cochran 1980). Confidence intervals (95%) were used to compare 1987 and 1988 PCB, DDE and dieldrin residues to historic levels in several species. The 1984 PCB levels in gulls were reported by Bishop *et al.* (1992) as Aroclor 1254:1260 1:1 mixtures, which the authors report appear to be approximately twice the amount obtained when all PCB congeners are summed. Therefore, a conversion factor of 0.46 (Turle *et al.* 1991) was used to calculate total PCBs from the levels reported. Orthogonal *t*-tests were used to compare mean values to identify spatial differences in 1988 herring gull and mallard egg PCB and DDE residues (Kirk 1969). One-way analysis of variance was used to compare PCB residues relative to time and sex in adult cormorants (Sokal and Rohlf 1969). Birds were grouped temporally in pre-nesting, laying, or incubating stages. Liver-to-carcass ratios in males and egg-to-carcass correlations in females for contaminant levels were calculated. Body burdens of PCBs lost through laying were calculated by the following formula:

$$\frac{(\text{Egg PCB wt X n})}{(\text{Egg PCB wt X n})+(\text{Carcass PCB wt})}$$

where
Egg PCB wt = total PCB lipid-weight in egg
n = number of eggs in clutch (3 or 4)
Carcass PCB wt = total PCB lipid-weight in carcass

One-way analysis of variance was used to estimate variance components within and between cormorant clutches (Sokal and Rohlf 1969).

RESULTS

Survey, 1987

PCBs and DDE were found at detectable levels in all soil/guano samples (Table 1). PCB levels in individual samples ranged from 0.30 ppm on Hat Island to 1.6 ppm on Jack Island. Residues of heptachlor epoxide just above the limit of detection were found on Spider and Jack Islands, and similarly, dieldrin was detected only on Gravel, Spider, and Jack Islands.

Avian eggs and carcasses contained detectable levels of oxychlordane, trans-nonachlor, cis-nonachlor, heptachlor epoxide, PCBs, DDD, DDE, DDT, and dieldrin (Tables 2-3). The 6.8 ppm (C.I. 3.9-9.6) mean PCB value in 1987 Forster's tern eggs from Kidney Island was similar ($P > 0.50$) to the 7.3 ppm found by Harris *et al.* (1993) in 1988, but lower ($P < 0.01$) than the 19.2 ppm found in 1983 along the western shore of Green Bay (Kubiak *et al.* 1989) and the 18.0 ppm found in 1978 on Long-tail Point (Heinz *et al.* 1985). The mean 1987 DDE level decreased from 2.9 ppm in 1978 to 1.2 ppm (C.I. 0.29-2.1). Dieldrin levels decreased from 0.25 ppm in 1978 to 0.09 (C.I. 0.03-0.15). PCB and DDE levels in common tern eggs followed the same pattern between 1977 (Lone Tree Island) and 1987. The reverse trend was true for dieldrin which increased from 0.06 in 1977 to 0.15 (C.I. 0.09-0.21) in 1987.

The shell-less herring gull egg had exceptionally high levels of PCBs (45 ppm) and DDE (29 ppm) compared to those found in 1984 on the same island (16 ppm and 7.1 ppm, respectively) (Bishop *et al.* 1992); however, some moisture loss had occurred and inflated the wet-weight residues. On a lipid-weight basis, these levels are still considerably higher than those found in 1988 (PCBs: 333 vs. 220 ppm, C.I. 122-317; DDE: 215 vs. 80 ppm, C.I. 57.1-104) (see below).

Metal concentrations for all 1987 samples are presented in Tables 4-6. Mean mercury levels are higher for both Forster's terns (2.5 ppm, C.I. 1.9-3.2) and common terns (1.6 ppm, C.I. 1.1-2.1) than 1977/1978 levels (0.37 ppm and 0.66 ppm, respectively) found in the lower bay (Heinz *et al.* 1985).

Survey, 1988

Detectable levels of oxychlordane, PCBs, and DDE were present in avian eggs collected from all islands in 1988. In addition, hexachlorobenzene (HCB), beta-BHC, delta-BHC, alpha-chlordane, gamma-chlordane, trans-nonachlor, cis-nonachlor, heptachlor epoxide, DDD, DDT, dieldrin, and mirex were found in various samples (Tables 7-14). Mean herring gull and mallard egg residues from individual islands were compared to detect any spatial differences in PCB and DDE levels. In herring gull eggs, no difference was indicated between Green Bay islands (Hat and Jack) and Lake Michigan islands (Spider, Gravel, and Hog) in levels of PCBs ($P > 0.50$) or DDE ($0.10 > P > 0.05$). Similarly, no differences were found in mallard eggs values for PCBs ($P > 0.50$) and DDE ($0.20 > P > 0.10$) between bay (Hat and Jack) and lake islands (Spider, Pilot, and Hog). No differences were found in PCB or DDE levels between 1) gulls on Hat vs. Jack Island, 2) mallards on Hat vs. Jack Island, 3) gulls on Spider vs. Gravel Island, 4) mallards on Spider vs. Pilot Island, and 5) mallards on Spider and Pilot vs. Hog Island ($P > 0.05$). There were differences in gull PCB levels ($P < 0.01$) and DDE levels ($P < 0.001$) between Spider and Gravel vs. Hog Island. The low residues found in gull eggs from Hog Island compared to all other sites suggests a systematic analytical error may be responsible for these differences.

Concentrations of organochlorines have decreased in some compartments of the Lake Michigan ecosystem over the last two decades, consistent with findings from other studies (Gilbertson 1983, Baumann and Whittle 1988). In 1988, the overall mean PCB value for Spider, Pilot, and Hog Island red-breasted merganser eggs of 9.6 ppm was lower (95% C.I. 7.1-12.3) compared to the 1977 mean of 25 ppm and the 1978 mean of 20 ppm in eggs collected from the same islands (Haseltine *et al.* 1981). The mean merganser DDE value in 1988 was 3.11 (95% C.I. 2.06-4.15) compared to 8.3 ppm in 1977 and 8.1 ppm in 1978. Dieldrin levels were also lower in

1988, with a mean value of 0.51 ppm (95% C.I. 0.33-0.69) compared to 0.86 in 1977 and 0.81 in 1978.

Concentrations of PCBs, DDE, and dieldrin in herring gulls were compared with 1977, 1978, and 1984 levels from Gravel Island, and 1984 levels from Hat and Spider Islands (Heinz *et al.* 1985, Bishop *et al.* 1992). The highest single egg concentration of PCBs (61 ppm) in 1988 was found on Gravel Island. The mean PCB value was lower on Gravel Island in 1988 (30 ppm, C.I. 6.5-53) compared to 1977 (100 ppm) and 1978 (65 ppm) values, but not to 1984 (20 ppm). The mean DDE value was lower on Gravel Island in 1988 (5.0 ppm, C.I. 2.9-7.1) compared to 1977 (33 ppm), 1978 (33 ppm), and 1984 (8.7 ppm). PCB and DDE levels were not different on Hat and Spider Islands between 1988 and 1984, and dieldrin levels in 1988 did not differ from any year or location.

Comparing contaminant levels in double-crested cormorant eggs from Fish Island to 1977 and 1978 values, the mean DDE value of 2.7 ppm (C.I. 0.30-5.1) was lower than the 1977 value of 5.3 ppm. PCBs and dieldrin levels did not differ between years.

PCB, DDE, and dieldrin levels in black-crowned night heron eggs from Cat Island were all lower compared to 1978 and 1980 levels (Heinz *et al.* 1985). PCBs decreased from 15.0 ppm in 1978 and 24.0 ppm in 1980 to 5.8 ppm (C.I. 0-13.4). DDE decreased from 4.0 ppm in 1978 and 5.4 ppm in 1980 to 0.65 ppm (C.I. 0.11-1.2). Dieldrin decreased from 0.18 ppm in 1978 and 0.15 ppm in 1980 to 0.04 ppm (C.I. 0.02-0.06). The 1.6 ppm PCB value found in the Spider Island egg was well below the 23 ppm found in a 1978 Spider Island egg.

Contaminant uptake by adult cormorants during nesting

All birds in the pre-nesting stage sample were males, suggesting that male cormorants arrive earlier than females on the breeding grounds. Body burdens of male cormorants approximately doubled between pre-laying and incubating stages (Table 15). PCB concentrations in male cormorant carcasses differed relative to time, corresponding to pre-nesting, laying and incubating stages ($P < 0.01$). PCB levels increased between pre-nesting and the laying/incubating stages (Table 16). Female cormorant PCB concentrations did not differ between laying and incubation stages ($P > 0.50$). There were no differences between sexes relative to laying, incubating, or the two stages combined ($P > 0.10$). There were no differences in DDT compounds between time intervals ($P > 0.50$). Other contaminants were present at low levels. The mean PCB concentration was 3.3 ppm in gut contents (Table 17).

Liver concentrations of contaminants in adult cormorants generally were lower than corresponding carcass concentrations (Table 18). Liver to carcass ratios are higher when reported on a lipid-weight versus a wet-weight basis. Lipid-weight comparisons between matrices are more useful due to the lipophilic nature of PCBs. This is important in terms of reproductive success because of the high lipid content of eggs which presumably act as sinks for lipophilic chemicals. Correlations for carcass to yolk and whole egg comparisons on a lipid-weight basis ranged from r = -0.14 for p,p'-DDT to r = 0.99 for oxychlordane (Table 19). Body burdens of PCBs lost through egg laying were 2.8-4.7% given three eggs per clutch and 3.7-6.2% given four eggs per clutch. The mean mass of PCBs lost through egg laying given a four-egg clutch compared to male body burdens were 3.1-9.8% in pre-laying, 2.2-5.9% in laying, and 2.0-5.0% in incubating stages.

Estimation of contaminant variation in whole clutches

Contaminant levels were different between clutches for all detectable contaminants ($P < 0.04$ HCB, p,p'-DDT; $P < 0.01$ remaining chemicals) (Table 20). The real intent of this study was to estimate relative contributions to variation for use in parallel studies. These estimates indicated that generally, variation between clutches was greater than variation within clutches (Table 21). This is certainly true for major contaminants in the system; between clutch variation was 93.4% for total DDTs, 89.0% for total PCBs, and 84.1% for dieldrin.

DISCUSSION

One purpose of these investigations was to provide a historical perspective to prior studies of contaminants in the avifauna of this area. Contaminant levels have demonstrably decreased from earlier studies. For example, PCBs in Forster's tern eggs have decreased by more than 60% between 1983 (19.2 ppm) and 1987 (6.8 ppm), DDE in merganser eggs has decreased by more than 60% between 1977/78 (8.2 ppm) and 1988 (3.1 ppm), and PCBs in merganser eggs has decreased similarly by more than 55% between 1977/78 (22 ppm) and 1988 (9.6 ppm). PCBs in herring gull eggs have decreased by more than 50% between 1978 (65 ppm) and 1988 (30 ppm). However, the decrease in herring gull eggs between 1984 and 1988 has been much less, and, in the case of PCBs and dieldrin, it was not detectable from background variation. The shell-less herring gull egg found on Hat Island had high levels of contaminants, especially DDE (29 ppm). Further study will be needed to determine whether or not contaminants are indeed decreasing more in terns and mergansers than in gulls.

As expected, piscivorous birds such as herring gulls, cormorants, and mergansers contain higher levels of organochlorines than species such as mallards and geese. The low levels (<1.0 ppm) of PCB and DDT compounds found in garter snake carcasses confirms earlier observations by Heinz *et al.* (1980) that this species is not a good indicator of organochlorine contamination. Although the sedentary nature of garter snakes is valuable in reflecting local contamination, they do not appear to concentrate the chemicals.

Mercury levels in terns may be of concern. The 1.6 and 2.5 ppm mean values are higher than 1970s levels, as well as the 0.86 ppm that Heinz (1979) found to impair reproduction in mallards. Analytical methods for mercury determination have been somewhat controversial, and this issue warrants further study.

The importance of local sources of contamination was clearly established by the study of contaminant uptake by adult cormorants. Body burdens of PCBs approximately doubled after arrival on the breeding grounds, due to contamination of their food items. The 3.3 ppm PCBs found in gut contents is considerably higher than the 0.2-0.4 ppm in forage fish suggested by Harris et al. (1993) as the no observable adverse effects level (NOEAL) for Forster's terns. In contrast, body burdens of DDT compounds were relatively constant. This may reflect the importance of the Green Bay ecosystem as an unusually high source of PCBs to migratory birds. The lack of change in DDT compounds may be a result of an equilibrium condition across a broad geographic area whereas birds returning to Green Bay are subject to unusually high levels of PCBs that require some time for equilibration with their environment.

Combined with Custer and Bunck's (1992) results on the foraging patterns of cormorants at Cat and Spider Islands, the present study demonstrates that the environment near the nesting colony is vital to determining the degree of contamination of these piscivorous birds. In addition, the clearance of contaminants from these birds via transfer to eggs is relatively small. Thus, it is unlikely that renesting or later nesting birds will be less subject to contaminant effects than are the early arriving or nesting birds. The differential arrival by sex was not anticipated and the similarity of body burdens by the beginning of the laying period may indicate an extremely rapid equilibration with the local environment. Alternatively, the arrival dates may not differ by more than a few days and we were unable to detect this due to our sampling schedule. If this is the case, then body burdens may indeed continue to increase throughout the summer. A fall sampling schedule would be instructive.

The study on contaminant variation in eggs from the same clutch was conducted to determine whether a single randomly selected egg from a clutch can be used to characterize the contaminant burden of the entire clutch. For the chemicals of concern, PCBs and DDTs, this certainly appeared to be true, with variation between clutches greater than variation within clutches. Consequently, it is possible to design retrospective studies in which nests are characterized by archiving single eggs with analysis of only those sample eggs of interest based on nest fate. This will result in precise tests of hypothesized relationships between contaminants and adverse reproductive effects. This may alleviate geographic confounding and "retroductive" inferences (Romesburg 1981:294) by allowing crucial experiments (Romesburg 1991:749) within contaminated colonies (a mensurative approach [Sinclair 1991:769]) instead of relying on correlations of effects between colonies (retroduction).

The levels of soil/guano contamination in these colonies are disturbing. Although there is no overall guidance on acceptable soil levels of organochlorines like PCBs, a target level of 1 ppm has been established for the Superfund cleanup of Crab Orchard National Wildlife Refuge (Leanne Moore, U.S. Fish and Wildlife Service, personal communication). Both Spider and Jack Island samples approached this level and, in addition to reinforcing the contaminated nature of these habitats, this raises interesting management questions concerning contaminants on Service lands. Because the source of the PCBs on these islands is predominately Lake Michigan and Green Bay fish, contaminants in those fish are not only affecting Service trust species, but also habitats on Service lands. When potential Natural Resource Damage Assessment (NRDA) activities are considered, injury to Service lands must be evaluated. Any actions the Service takes will be strengthened considerably if it can be demonstrated that Service lands are affected as well as trust species. The Service will also be able to claim status as a land management agency with interests in water, air, and geological resources.

CONCLUSIONS AND RECOMMENDATIONS

Despite the wilderness designation of Gravel and Green Bay National Wildlife Refuges, these islands are affected by the by-products of industrial civilization. The biota and habitats of these Service lands are contaminated and degraded. Further studies should be considered in order to assess the health of Service lands and trust species inhabiting them. Long-term monitoring of the biota of these refuges should be continued in order to track progress in ecosystem remediation. These islands are one of the few places in Lake Michigan/Green Bay where a historic data base exists on trust species. This monitoring program should focus on both the biology and contaminant burdens of mergansers and cormorants. Other agencies are tracking gulls on an extensive basis and gulls can be used as needed to compare results with those from cormorants and mergansers.

Equally important is the need for critical tests of the cause and effect relationships between putative reproductive impairments and organochlorine chemicals. Evidence of these relationships are needed both for management purposes and potential use in NRDA actions. In the absence of solid scientific results using accepted hypothetico-deductive techniques, NRDA actions may be compromised by unnecessary litigation about causation based on inferences from correlations.

REFERENCES

Baumann, P.C. and D.M. Whittle. 1988. The status of selected organics in the Laurentian Great Lakes. An overview of DDT, PCBs, dioxins, furans, and aromatic hydrocarbons. Aquat.Toxicol. 11:241-257.

Bishop, C.A., D.V. Weseloh, N.M. Burgess, J. Struger, R.J. Norstrom, R. Turle, and K.A. Logan. 1992. An atlas of contaminants in eggs of fish-eating colonial birds of the Great Lakes (1970-1988). Vol. I. Technical Report Series No. 152, Canadian Wildlife Service, Ontario Region.

Custer, T.W., and C. Bunck. 1992. Feeding flights of breeding double-crested cormorants at two Wisconsin Colonies. J.Field Ornithol. 63:203-211.

Evans, M.S. ed. 1988. Toxic Contaminants and Ecosystem Health: A Great Lakes Focus, Vol. 21. Wiley Series Advances in Environmental Science and Technology. John Wiley and Sons. New York, New York.

Gilbertson, M. 1983. Etiology of chick edema disease in herring gulls in the lower Great Lakes. Chemosphere 12:357-370.

Harris, H.J., T.C. Erdman, G.T. Ankley, and K.B. Lodge. 1993. Measures of reproductive success and polychlorinated biphenyl residues in eggs and chicks of Forster's terns on Green Bay, Lake Michigan, Wisconsin-1988. Arch.Environ.Contam.Toxicol. 25:304-314.

Haseltine, S.D., G.H. Heinz, W.L. Reichel, and J.F. Moore. 1981. Organochlorine and metal residues in eggs of waterfowl nesting on islands in Lake Michigan off Door County, Wisconsin, 1977-1978. Pestic.Monit.J. 15(2):90-97.

Heinz, G.H. 1979. Methylmercury: reproductive and behavioral effects on three generations of mallard ducks. J.Wildl.Manage. 43(2):394-401.

Heinz, G.H., S.D. Haseltine, R.J. Hall, and A.J. Krynitsky. 1980. Organochlorine and mercury residues in snakes from Pilot and Spider Islands, Lake Michigan-1978. Bull.Environ.Contam.Toxicol. 25:738-743.

Heinz, G.H., S.D. Haseltine, W.L. Reichel, and G.L. Hensler. 1983. Relationships of environmental contaminants to reproductive success in red-breasted mergansers *Mergus serrator* from Lake Michigan. Environ.Pollut. (Ser.A) 32:211-232.

Heinz, G.H., T.C. Erdman, S.D. Haseltine, and C. Stafford. 1985. Contaminant levels in colonial waterbirds from Green Bay and Lake Michigan, 1975-80. Environ.Monitor.Assess. 5:223-236.

Heinz, G.H., D.S. Miller, B. Ebert, K.L. Stromborg. In prep. Declines in organochlorines in eggs of red-breasted mergansers from Lake Michigan, 1977-78 versus 1990.

Kirk, R.E. 1969. Experimental Design: Procedures for the Behavioral Sciences. Wadsworth Publishing Company, Inc. Belmont, California.

Kubiak, T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.L. Stalling, J.A. Trick, L. Sileo, D.E. Docherty, and T.C. Erdman. 1989. Microcontaminants and reproductive impairment of the Forster's tern on Green Bay, Lake Michigan-1983. Arch.Environ.Contam.Toxicol. 18:706-727.

Larson, J. 1991. Reproduction and Developmental Anomalies in Double-crested Cormorants (*Phalacrocorax auritus*) on Lake Michigan: An Environmental Contaminants Study. Master's Thesis, University of Wisconsin, Madison, Wisconsin.

Romesburg, H.C. 1981. Wildlife science: gaining reliable knowledge. J. Wildl.Manage. 45(2):293-313.

__________ 1991. On improving the natural resources and environmental sciences. J.Wildl.Manage. 55(4):744-756.

Sinclair, A.R.E. 1991. Science and the practice of wildlife management. J. Wildl.Manage. 55(4):767-773.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical Methods. 7th ed. The Iowa State University Press. Ames, Iowa.

Sokal, R.R. and F.J. Rohlf. 1969. Biometry - The principles and practice of statistics in biological research. W.H. Freeman and Company. San Francisco, California.

Stickel, L.F., S.N. Wiemeyer, and L.J. Blus. 1973. Pesticide residues in eggs of wild birds: adjustment for loss of moisture and lipid. Bull.Environ. Contam.Toxicol. 9:193-196.

Taft, W.H. Executive Order No. 1487. February 21, 1912.

__________ Executive Order No. 1678. January 9, 1913.

Tillitt, D.E., G.T. Ankley, J.P. Giesy, J.P. Ludwig, H. Kurita-Matsuba, D.V. Weseloh, P.S. Ross, C.A. Bishop, L. Sileo, K.L. Stromborg, J. Larson, and T.J. Kubiak. 1992. Polychlorinated biphenyl residues and egg mortality in double-crested cormorants from the Great Lakes. Environ.Toxicol.Chem. 11:1281-1288.

Turle, R., R.J. Norstrom, and B. Collins. 1991. Comparison of PCB quantitation methods: Re-analysis of archived specimens of herring gull eggs from the Great Lakes. Chemosphere 22(1-2):201-213.

White, D.H. and E. Cromartie. 1977. Residues of environmental pollutants and shell thinning in merganser eggs. Wilson Bull. 89(4):532-542.

Table 1. Chemical concentrations (ppm, wet-weight) in soil/guano collected from islands in Green Bay and Lake Michigan during 1987 (n = 1).

	Gravel	Spider	Hat	Hat	Jack	Jack
HCB	ND	ND	ND	ND	ND	ND
alpha-BHC	ND	ND	ND	ND	ND	ND
beta-BHC	ND	ND	ND	ND	ND	ND
delta-BHC	ND	ND	ND	ND	ND	ND
gamma-BHC	ND	ND	ND	ND	ND	ND
Oxychlordane	ND	ND	ND	ND	ND	ND
alpha-chlordane	ND	ND	ND	ND	ND	ND
gamma-chlordane	ND	ND	ND	ND	ND	ND
trans-nonachlor	ND	ND	ND	ND	ND	ND
cis-nonachlor	ND	ND	ND	ND	ND	ND
Heptachlor epoxide	ND	0.02	ND	ND	ND	0.02
Total PCBs	0.37	0.88	0.30	0.63	0.36	1.6
o,p'-DDE	ND	ND	ND	ND	ND	ND
p,p'-DDE	0.14	0.29	0.08	0.30	0.10	0.47
o,p'-DDD	ND	ND	ND	ND	ND	ND
p,p'-DDD	ND	ND	ND	ND	ND	ND
o,p'-DDT	ND	ND	ND	ND	ND	ND
p,p'-DDT	ND	ND	ND	ND	ND	ND
Dieldrin	0.03	0.05	ND	ND	ND	0.05
Toxaphene	ND	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND	ND
Mirex	ND	ND	ND	ND	ND	ND
Weight (g)	840	574	896	786	784	592
% Moisture	14.6	47.4	53.8	48.0	35.8	60.0

Table 2. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Kidney Island, Green Bay during 1987. [1]

	Forster's tern (n = 5)	Common tern (n = 5)
HCB	ND	ND
alpha-BHC	ND	ND
beta-BHC	ND	ND
delta-BHC	ND	ND
gamma-BHC	ND	ND
Oxychlordane	0.032±0.019 [2]	0.038±0.015
alpha-chlordane	ND	ND
gamma-chlordane	ND	ND
trans-nonachlor	0.13±0.069	0.036±0.011
cis-nonachlor	0.062±0.036	0.026±0.011
Heptachlor epoxide	0.046±0.025	0.056±0.031
Total PCBs	6.8±2.3	10.3±3.70
o,p'-DDE	ND	ND
p,p'-DDE	1.2±0.74	1.7±0.81
o,p'-DDD	ND	ND
p,p'-DDD	0.024±0.027	0.034±0.0055
o,p'-DDT	ND	ND
p,p'-DDT	ND	ND
Dieldrin	0.090±0.048	0.15±0.047
Toxaphene	ND	ND
Endrin	ND	ND
Mirex	ND	ND
Weight (g)	19.4±2.3	17.0±1.7
% Moisture	78.1±1.9	78.2±1.8
% Lipid	8.1±1.6	7.6±2.3

[1] Samples were not corrected for moisture loss.
[2] Mean ± s.d.

Table 3. Chemical concentrations (ppm, wet-weight) in miscellaneous biota collected from islands in Green Bay and Lake Michigan during 1987 (n = 1).

	Mallard carcass Kidney Island	Pintail carcass Kidney Island	Gadwall carcass Kidney Island	Cormorant carcass Spider Island	Black-crowned night heron carcass Cat Island	Black-crowned night heron carcass Cat Island	Herring gull egg Hat Island
HCB	ND	ND	ND	ND	ND	ND	ND
alpha-BHC	ND	ND	ND	ND	ND	ND	ND
beta-BHC	ND	ND	ND	ND	ND	ND	ND
delta-BHC	ND	ND	ND	ND	ND	ND	ND
gamma-BHC	ND	ND	ND	ND	ND	ND	ND
Oxychlordane	ND	ND	ND	0.16	0.06	0.05	1.6
alpha-chlordane	ND	ND	ND	ND	ND	ND	ND
gamma-chlordane	ND	ND	ND	ND	ND	ND	ND
trans-nonachlor	0.01	0.01	0.01	0.08	0.29	0.12	0.13
cis-nonachlor	ND	ND	ND	0.16	0.17	0.07	0.17
Heptachlor epoxide	ND	ND	ND	0.31	0.08	0.03	0.78
Total PCBs	2.4	0.93	1.0	10	11	8.0	45
o,p'-DDE	ND	ND	ND	ND	ND	ND	ND
p,p'-DDE	0.17	0.08	0.09	3.4	2.4	2.5	29
o,p'-DDD	ND	ND	ND	ND	ND	ND	ND
p,p'-DDD	ND	ND	ND	0.15	0.12	0.02	0.46
o,p'-DDT	ND	ND	ND	ND	ND	ND	0.17
p,p'-DDT	ND	ND	ND	ND	ND	ND	1.5
Dieldrin	ND	0.01	0.01	1.0	0.13	0.09	1.2
Toxaphene	ND	ND	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND	ND	ND
Mirex	ND	ND	ND	ND	ND	ND	ND
Weight (g)	459	201	152	2170	572	365	45.8
% Moisture	67.8	71.6	70.0	66.8	65.4	72.2	63.9
% Lipid	1.3	1.8	1.9	7.9	9.7	1.2	13.5

Table 4. Metal concentrations (ppm, dry-weight) in soil/guano collected from islands in Green Bay and Lake Michigan during 1987 (n = 1).

	Gravel	Spider	Hat	Hat	Jack	Jack
Aluminum	583	752	3050	2790	2720	1940
Arsenic	0.57	0.48	0.59	1.2	0.83	0.93
Barium	5.9	15.9	36.1	44.4	36.4	40.1
Beryllium	ND	ND	0.3	0.3	0.2	0.1
Boron	ND	4	5	10	5	6.7
Cadmium	ND	1.0	0.4	0.95	0.70	1.1
Chromium	3	2	4.6	5.2	4.6	4.0
Copper	2.8	10	9.6	16	9.7	21
Iron	1870	1350	2650	3280	3780	4000
Lead	ND	14	13	23	13	16
Magnesium	5330	6960	63200	57900	43900	13700
Manganese	33.7	72.2	88.3	224	209	217
Mercury	0.069	0.27	0.19	0.27	0.12	0.31
Molybdenum	ND	ND	ND	ND		ND
Nickel	ND	ND	2	3	3	2
Selenium	ND	ND	ND	ND		ND
Silver	ND	ND	ND	ND	ND	ND
Strontium	32.2	76.4	36.3	35.6	23.0	86.0
Thallium	ND	ND	ND	ND	ND	ND
Vanadium	4.1	2.1	4.2	5.2	4.2	3.5
Zinc	89.7	306	70.4	151	113	355
% Moisture	20.0	44.2	52.5	44.7	40.1	60.9

Table 5. Metal concentrations (ppm, dry-weight) in avian eggs collected from Kidney Island, Green Bay during 1987.[1]

	Forster's tern (n = 5)	Common tern (n = 5)
Aluminum	5.2±7.2 [2]	2.6±2.5
Arsenic	0.080±0.067	ND
Beryllium	ND	ND
Cadmium	ND	ND
Chromium	0.70±1.2	0.43±0.54
Copper	3.6±0.42	3.5±0.34
Iron	124±28.8	132±34.3
Lead	0.53±0.71	ND
Manganese	1.8±0.49	2.3±0.72
Mercury	2.5±0.53	1.6±0.40
Nickel	0.42±0.55	0.18±0.084
Thallium	ND	ND
Zinc	55.7±3.21	63.3±7.87
% Moisture	77.0±1.8	76.8±2.1

[1] Samples were not corrected for moisture loss.
[2] Mean ± s.d.

Table 6. Metal concentrations (ppm, dry-weight) in miscellaneous biota collected from islands in Green Bay and Lake Michigan during 1987 (n = 1).

	Mallard carcass Kidney Island	Pintail carcass Kidney Island	Gadwall carcass Kidney Island	Cormorant carcass Spider Island	Black-crowned night heron carcass Cat Island	Black-crowned night heron carcass Cat Island	Herring gull egg Hat Island
Aluminum	372	330	159	20	47.3	65.3	3.4
Arsenic	0.83	ND	ND	ND	ND	ND	ND
Beryllium	0.02	0.03	0.01	ND	ND	0.01	ND
Cadmium	0.089	0.04	0.07	0.17	0.05	0.06	ND
Chromium	9.7	22.6	9.5	2.1	6.0	38.0	ND
Copper	25.9	36.4	39.9	7.64	17.9	30.3	3.49
Iron	862	632	403	309	219	418	102
Lead	420	1.9	1.8	17	ND	ND	ND
Manganese	16.9	18.6	13.2	2.89	3.36	3.95	2.2
Mercury	1.07	1.7	2.0	2.5	1.2	0.897	0.508
Nickel	1.6	1.9	3.7	0.74	1.4	1.3	0.2
Thallium	ND	ND	ND	0.6	ND	ND	ND
Zinc	150	147	157	70.1	106	177	61.5
% Moisture	68.5	70.2	72.7	66.9	70.4	71.4	63.9

Table 7. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Cat Island, Green Bay during 1988.

	Canada goose [1] (n = 4)	Black-crowned night heron (n = 6)
HCB	ND	ND
alpha-BHC	ND	ND
beta-BHC	ND	ND
delta-BHC	ND	ND
gamma-BHC	ND	ND
Oxychlordane	ND	0.051±0.045
alpha-chlordane	ND	ND
gamma-chlordane	ND	0.033±0.029
trans-nonachlor	ND	ND
cis-nonachlor	ND	ND
Heptachlor epoxide	ND	0.037±0.040
o,p'-DDE	ND	ND
p,p'-DDE	0.063±0.0050 [2]	0.65±0.52
o,p'-DDD	ND	ND
p,p'-DDD	ND	0.041±0.032
o,p'-DDT	ND	ND
p,p'-DDT	ND	0.033±0.029
Total DDTs	0.083±0.0096	0.73±0.58
Total Cl2 BIPH	ND	ND
Total Cl3 BIPH	ND	0.22±0.24
Total Cl4 BIPH	0.12±0.071	1.8±2.1
Total Cl5 BIPH	0.073±0.0096	1.6±1.9
Total Cl6 BIPH	0.093±0.019	1.5±2.0
Total Cl7 BIPH	ND	0.50±0.87
Total Cl8 BIPH	ND	0.14±0.24
Total Cl9 BIPH	ND	0.030±0.021
Total Cl10 BIPH	ND	ND
Total PCBs	ND	5.8±7.2
Dieldrin	ND	0.040±0.021
Toxaphene	ND	ND
Endrin	ND	ND
Mirex	ND	ND
Weight(g)	144.0±9.3	39.0±3.0
% Moisture	67.0±12.4	81.7±1.7
% Lipid	10.5±2.8	5.2±0.6

[1] Samples were not corrected for moisture loss.
[2] Mean ± s.d.

Table 8. Chemical concentrations (ppm, wet-weight) in biota collected from Hat Island, Green Bay during 1988.

	Mallard egg (*n* = 4)	Herring gull egg [1] (*n* = 4)	Garter snake carcass (*n* = 1)
HCB	ND	ND	ND
alpha-BHC	ND	ND	ND
beta-BHC	ND	ND	ND
delta-BHC	ND	ND	ND
gamma-BHC	ND	ND	ND
Oxychlordane	0.045±0.046	0.28±0.14	ND
alpha-chlordane	ND	ND	ND
gamma-chlordane	ND	ND	ND
trans-nonachlor	0.054±0.064 [2]	0.095±0.048	ND
cis-nonachlor	0.027±0.011	0.073±0.026	ND
Heptachlor epoxide	ND	0.20±0.071	ND
o,p'-DDE	ND	0.073±0.021	ND
p,p'-DDE	0.73±0.80	5.7±1.1	0.34
o,p'-DDD	ND	ND	ND
p,p'-DDD	ND	0.044±0.038	ND
o,p'-DDT	ND	0.034±0.018	ND
p,p'-DDT	0.037±0.018	0.064±0.036	ND
Total DDTs	0.78±0.82	5.9±1.1	0.34
Total Cl2 BIPH	ND	ND	ND
Total Cl3 BIPH	ND	0.20±0.079	ND
Total Cl4 BIPH	0.24±0.33	3.4±1.5	0.11
Total Cl5 BIPH	0.36±0.45	3.8±1.3	0.15
Total Cl6 BIPH	0.44±0.49	5.5±1.2	0.29
Total Cl7 BIPH	0.13±0.18	2.3±0.54	0.06
Total Cl8 BIPH	ND	0.41±0.10	ND
Total Cl9 BIPH	ND	ND	ND
Total Cl10 BIPH	ND	ND	ND
Total PCBs	1.1±1.5	15.6±4.34	0.61
Dieldrin	ND	0.60±0.30	ND
Toxaphene	ND	ND	ND
Endrin	ND	ND	ND
Mirex	ND	ND	ND
Weight (g)	50.6±2.9	87.3±7.5 (*n*=3)	71.0
% Moisture	68.1±1.3	76.3±0.5	71.4
% Lipid	12.1±2.2	7.1±0.9	7.9

[1] Samples were not corrected for moisture loss.
[2] Mean ± s.d.

Table 9. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Jack Island, Green Bay during 1988.

	Mallard (n = 4)	Canada goose [1] (n = 2)	Herring gull [1] (n = 6)
HCB	ND	ND	0.11±0.068
alpha-BHC	ND	ND	ND
beta-BHC	ND	ND	0.039±0.035
delta-BHC	ND	ND	0.034±0.023
gamma-BHC	ND	ND	ND
Oxychlordane	0.082±0.12 [2]	ND	0.30±0.10
alpha-chlordane	ND	ND	0.034±0.023
gamma-chlordane	ND	ND	0.034±0.023
trans-nonachlor	0.10±0.16	ND	0.11±0.060
cis-nonachlor	ND	ND	0.093±0.040
Heptachlor epoxide	0.037±0.032	ND	0.23±0.11
o,p'-DDE	ND	ND	0.036±0.027
p,p'-DDE	1.6±2.4	ND	4.2±1.5
o,p'-DDD	ND	ND	0.067±0.058
p,p'-DDD	ND	ND	0.083±0.065
o,p'-DDT	ND	ND	0.045±0.038
p,p'-DDT	0.063±0.084	ND	0.11±0.057
Total DDTs	1.6±2.5	0.055±0.071	4.5±1.6
Total Cl2 BIPH	ND	ND	ND
Total Cl3 BIPH	0.037±0.032	0.038±0.018	0.15±0.085
Total Cl4 BIPH	0.72±1.1	0.21±0.26	3.1±1.7
Total Cl5 BIPH	0.43±0.37	ND	4.3±1.6
Total Cl6 BIPH	1.3±2.1	0.05±0.00	5.6±1.8
Total Cl7 BIPH	0.37±0.62	ND	3.6±1.4
Total Cl8 BIPH	0.089±0.14	ND	1.6±0.75
Total Cl9 BIPH	ND	ND	0.25±0.16
Total Cl10 BIPH	ND	ND	0.11±0.10
Total PCBs	2.9±4.4	ND	18.8±7.15
Dieldrin	0.047±0.051	ND	0.42±0.086
Toxaphene	ND	ND	ND
Endrin	ND	ND	ND
Mirex	ND	ND	0.078±0.041
Weight (g)	52.1±4.7	126.0±4.2	96.4±9.0
% Moisture	68.3±0.4	67.0±0.5	74.8±1.7
% Lipid	12.8±1.9	12.9±0.5	6.0±2.2

[1] Samples were not corrected for moisture loss.
[2] Mean ± s.d.

Table 10. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Spider Island, Lake Michigan during 1988.

	Mallard (n = 5)	Gadwall (n = 2)	Canada goose[1] (n = 2)	Black-crowned night heron (n = 1)	Herring gull[1] (n = 4)	Red-breasted merganser (n = 10)
HCB	ND	ND	ND	ND	ND	ND
alpha-BHC	ND	ND	ND	ND	ND	ND
beta-BHC	ND	ND	ND	ND	ND	ND
delta-BHC	ND	ND	ND	ND	ND	ND
gamma-BHC	ND	ND	ND	ND	ND	ND
Oxychlordane	0.038±0.024	ND	ND	0.08	0.23±0.19	0.18±0.10
alpha-chlordane	ND	ND	ND	ND	ND	0.030±0.023
gamma-chlordane	ND	ND	ND	ND	ND	0.031±0.026
trans-nonachlor	ND	ND	ND	0.09	0.085±0.045	0.14±0.12
cis-nonachlor	ND	ND	ND	ND	0.044±0.038	0.073±0.11
Heptachlor epoxide	ND	ND	ND	ND	0.20±0.13	0.14±0.055
o,p'-DDE	ND	ND	ND	ND	0.051±0.019	0.16±0.22
p,p'-DDE	0.44±0.18 [2]	0.13±0.068	0.090±0.042	0.46	6.2±4.1	2.1±0.58
o,p'-DDD	ND	ND	ND	ND	ND	0.030±0.023
p,p'-DDD	ND	ND	ND	ND	0.041±0.033	0.13±0.063
o,p'-DDT	ND	ND	ND	ND	0.049±0.048	0.048±0.044
p,p'-DDT	ND	ND	ND	ND	0.034±0.018	0.12±0.067
Total DDTs	0.49±0.21	0.15±0.056	0.10±0.05	0.50	6.3±4.1	2.6±0.77
Total Cl2 BIPH	ND	ND	ND	ND	ND	ND
Total Cl3 BIPH	0.16±0.24	ND	ND	ND	0.11±0.026	0.10±0.060
Total Cl4 BIPH	1.0±1.4	ND	ND	0.29	5.2±5.5	0.88±0.30
Total Cl5 BIPH	1.0±1.2	ND	0.09±0.00	0.55	3.1±1.7	1.6±0.86
Total Cl6 BIPH	0.92±0.93	0.12±0.036	0.14±0.04	0.55	5.4±4.0	2.6±1.2
Total Cl7 BIPH	0.16±0.16	ND	0.043±0.025	0.15	2.1±1.6	1.0±0.49
Total Cl8 BIPH	0.035±0.020	ND	ND	ND	0.41±0.34	0.25±0.23
Total Cl9 BIPH	ND	ND	ND	ND	ND	ND
Total Cl10 BIPH	ND	ND	ND	ND	ND	ND
Total PCBs	3.3±3.9	ND	ND	1.6	16.4±8.78	6.5±2.6
Dieldrin	0.036±0.021	ND	ND	ND	0.44±0.22	0.36±0.29
Toxaphene	ND	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND	ND
Mirex	ND	ND	ND	ND	ND	ND
Weight (g)	44.7±5.5	44.5±2.5	135.0±10.0	43.8	93.2±4.3	72.9±4.5
% Moisture	69.0±4.3	68.2±0.8	66.7±2.9	81.9	76.6±0.7	69.5±4.2
% Lipid	10.5±1.8	25.2±14.9	12.8±1.8	4.6	7.1±1.5	9.5±5.9

[1] Samples were not corrected for moisture loss.
[2] Mean ± s.d.

Table 11. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Gravel Island, Lake Michigan during 1988.

	Herring gull [1] (n = 5)
HCB	0.094±0.039 [2]
alpha-BHC	ND
beta-BHC	0.030±0.011
delta-BHC	0.032±0.016
gamma-BHC	ND
Oxychlordane	0.69±0.61
alpha-chlordane	0.051±0.045
gamma-chlordane	0.070±0.064
trans-nonachlor	0.24±0.19
cis-nonachlor	0.17±0.13
Heptachlor epoxide	0.55±0.47
o,p'-DDE	ND
p,p'-DDE	5.0±1.7
o,p'-DDD	0.13±0.049
p,p'-DDD	0.19±0.13
o,p'-DDT	0.13±0.15
p,p'-DDT	0.18±0.11
Total DDTs	5.7±1.7
Total Cl2 BIPH	ND
Total Cl3 BIPH	0.36±0.42
Total Cl4 BIPH	5.1±4.4
Total Cl5 BIPH	8.0±6.3
Total Cl6 BIPH	9.4±6.4
Total Cl7 BIPH	4.6±1.3
Total Cl8 BIPH	1.7±0.23
Total Cl9 BIPH	0.28±0.067
Total Cl10 BIPH	0.090±0.032
Total PCBs	29.5±18.6
Dieldrin	0.88±0.70
Toxaphene	ND
Endrin	ND
Mirex	0.071±0.035
Weight (g)	104.2±6.9
% Moisture	76.0±1.1
% Lipid	6.7±1.2

[1] Samples were not corrected for moisture loss.
[2] Mean ± s.d.

Table 12. Chemical concentrations (ppm, wet-weight) in biota collected from Pilot Island, Lake Michigan during 1988.

	Mallard egg (n = 1)	Red-breasted merganser egg (n = 8)	Garter snake carcass (n = 2)
HCB	ND	ND	ND
alpha-BHC	ND	ND	ND
beta-BHC	ND	ND	ND
delta-BHC	ND	ND	ND
gamma-BHC	ND	ND	ND
Oxychlordane	ND	0.32±0.19 [1]	ND
alpha-chlordane	ND	0.026±0.0082	ND
gamma-chlordane	ND	ND	ND
trans-nonachlor	ND	0.28±0.16	ND
cis-nonachlor	ND	0.098±0.069	ND
Heptachlor epoxide	ND	0.30±0.23	ND
o,p'-DDE	ND	0.040±0.048	ND
p,p'-DDE	0.34	3.5±1.4	0.14±0.0071
o,p'-DDD	ND	ND	ND
p,p'-DDD	ND	0.21±0.092	ND
o,p'-DDT	ND	0.031±0.022	ND
p,p'-DDT	ND	0.11±0.12	ND
Total DDTs	0.35	3.8±1.5	0.15±0.014
Total Cl2 BIPH	ND	ND	ND
Total Cl3 BIPH	ND	0.17±0.083	ND
Total Cl4 BIPH	0.13	1.7±1.0	ND
Total Cl5 BIPH	0.20	2.7±1.7	0.038±0.018
Total Cl6 BIPH	0.22	5.0±3.1	0.080±0.014
Total Cl7 BIPH	0.05	1.5±0.75	ND
Total Cl8 BIPH	ND	0.30±0.17	ND
Total Cl9 BIPH	ND	0.083±0.16	ND
Total Cl10 BIPH	ND	ND	ND
Total PCBs	0.60	11.5±6.28	ND
Dieldrin	ND	0.59±0.54	ND
Toxaphene	ND	ND	ND
Endrin	ND	ND	ND
Mirex	ND	0.026±0.0086	ND
Weight (g)	49.1	68.7±2.8	77.5±12.0
% Moisture	65.5	66.1±1.0	68.4±1.7
% Lipid	13.1	13.8±4.2	8.4±0.2

[1] Mean ± s.d.

Table 13. Chemical concentrations (ppm, wet-weight) in avian eggs collected from Hog Island, Lake Michigan during 1988.

	Mallard [1] (n = 15)	Canada goose [2] (n = 1)	Double-crested cormorant (n = 2)	Herring gull[2] (n = 5)	Red-breasted merganser (n = 7)
HCB	ND	ND	ND	ND	0.030±0.019
alpha-BHC	ND	ND	ND	ND	ND
beta-BHC	ND	ND	0.063±0.025	ND	0.054±0.059
delta-BHC	ND	ND	0.043±0.028	ND	0.030±0.018
gamma-BHC	ND	ND	ND	ND	ND
Oxychlordane	ND	ND	0.096±0.072	0.036±0.025	0.32±0.37
alpha-chlordane	ND	ND	0.039±0.023	ND	0.089±0.18
gamma-chlordane	ND	0.05	0.034±0.017	ND	0.026±0.0089
trans-nonachlor	0.026±0.013	ND	0.043±0.030	0.046±0.047	0.20±0.28
cis-nonachlor	ND	ND	0.043±0.030	ND	0.12±0.11
Heptachlor epoxide	ND	ND	0.11±0.021	ND	0.33±0.30
o,p'-DDE	ND	ND	ND	ND	0.095±0.19
p,p'-DDE	0.27±0.18 [3]	ND	3.3±2.3	0.52±0.23	4.0±4.5
o,p'-DDD	ND	ND	0.071±0.068	ND	0.040±0.030
p,p'-DDD	ND	ND	0.14±0.11	ND	0.26±0.22
o,p'-DDT	ND	ND	0.11±0.018	ND	0.051±0.039
p,p'-DDT	ND	ND	0.10±0.011	ND	0.28±0.36
Total DDTs	0.30±0.19	0.07	3.8±2.4	0.54±0.23	4.7±4.9
Total Cl2 BIPH	ND	ND	ND	ND	ND
Total Cl3 BIPH	ND	1.4	0.20±0.029	ND	0.21±0.19
Total Cl4 BIPH	0.072±0.063	0.45	1.4±0.98	0.50±0.50	2.2±1.7
Total Cl5 BIPH	0.18±0.22	0.23	1.7±0.00	0.37±0.24	3.9±5.1
Total Cl6 BIPH	0.18±0.11	0.06	3.3±0.40	0.47±0.29	3.9±2.3
Total Cl7 BIPH	0.041±0.025	0.05	1.8±0.44	0.15±0.12	1.6±1.2
Total Cl8 BIPH	ND	ND	0.88±0.22	0.049±0.033	0.31±0.21
Total Cl9 BIPH	ND	ND	0.12±0.0017	ND	0.038±0.019
Total Cl10 BIPH	ND	ND	0.095±0.056	ND	ND
Total PCBs	0.45±0.32	2.2	9.4±1.4	1.5±1.1	12.1±8.6
Dieldrin	0.052±0.058	0.07	0.24±0.11	ND	0.64±0.51
Toxaphene	ND	ND	ND	ND	ND
Endrin	ND	ND	ND	ND	ND
Mirex	ND	ND	ND	ND	0.026±0.0079
Weight (g)	45.2±7.5 n=14	100.0	45.5±1.0	95.8±9.0	71.1±3.7
% Moisture	66.9±1.5	64.0	85.0±1.0	75.9±0.7	68.8±5.4
% Lipid	15.3±5.6	15.2	4.6	7.4±0.5	10.9±5.9

[1] Two samples were not corrected for moisture loss.
[2] Samples were not corrected for moisture loss.
[3] Mean ± s.d.

Table 14. Chemical concentrations (ppm, wet-weight) in cormorant eggs collected from Fish Island, Lake Michigan during 1988.

	Double-crested cormorant [1] (n = 5)
HCB	ND
alpha-BHC	ND
beta-BHC	ND
delta-BHC	ND
gamma-BHC	ND
Oxychlordane	0.11±0.081 [2]
alpha-chlordane	ND
gamma-chlordane	ND
trans-nonachlor	0.049±0.032
cis-nonachlor	0.062±0.084
Heptachlor epoxide	0.085±0.056
o,p'-DDE	ND
p,p'-DDE	2.7±1.9
o,p'-DDD	ND
p,p'-DDD	0.045±0.029
o,p'-DDT	0.034±0.022
p,p'-DDT	0.041±0.026
Total DDTs	2.8±2.0
Total Cl2 BIPH	ND
Total Cl3 BIPH	0.068±0.054
Total Cl4 BIPH	1.8±1.5
Total Cl5 BIPH	1.9±0.68
Total Cl6 BIPH	3.6±2.1
Total Cl7 BIPH	1.4±1.0
Total Cl8 BIPH	0.31±0.23
Total Cl9 BIPH	ND
Total Cl10 BIPH	ND
Total PCBs	9.0±5.4
Dieldrin	0.30±0.26
Toxaphene	ND
Endrin	ND
Mirex	0.030±0.014
Weight (g)	47.5±5.7
% Moisture	87.4±4.0
% Lipid	3.8±0.7

[1] One sample was not corrected moisture loss.
[2] Mean ± s.d.

Table 15. Body burdens of PCBs (mg) in adult male double-crested cormorants collected from Cat Island, Green Bay during 1988.

	MALES		
Sample	Pre-nesting	Laying	Incubating
1	81.4	136.5	139.1
2	61.8	206.1	270.6
3	118.2	160.6	109.6
4	55.7	92.4	184.4
5	73.8	144.8	175.1
6	65.4	248.4	229.9
7	178.4		
8	88.2		
$\bar{x}$ =	90.4	164.8	184.8

Table 16. Chemical concentrations (ppm, wet-weight) in adult double-crested cormorants collected from Cat Island, Green Bay during 1988.

	MALES			FEMALES	
	Pre-nesting (n = 8)	Laying (n = 6)	Incubating (n = 6)	Laying (n = 4)	Incubating (n = 4)
HCB	0.029±0.023 [1]	0.018±0.0075	0.015±0.0055	0.030±0.020	0.023±0.0050
alpha-BHC	0.014±0.0062	0.0075±0.0027	0.0058±0.0020	0.0088±0.0025	0.0063±0.0025
beta-BHC	0.028±0.016	0.017±0.0082	0.018±0.0088	0.023±0.013	0.019±0.013
delta-BHC	ND	ND	ND	ND	ND
gamma-BHC	0.0094±0.0018	0.013±0.014	ND	0.0075±0.0029	0.0063±0.0025
Oxychlordane	0.11±0.030	0.14±0.018	0.13±0.041	0.15±0.065	0.11±0.039
alpha-chlordane	0.083±0.0055	0.033±0.0082	0.050±0.022	0.035±0.013	0.045±0.025
gamma-chlordane	ND	ND	ND	ND	ND
trans-nonachlor	0.056±0.036	0.027±0.0082	0.040±0.022	0.030±0.014	0.048±0.025
cis-nonachlor	0.10±0.055	0.080±0.033	0.095±0.030	0.095±0.038	0.12±0.063
Heptachlor epoxide	0.14±0.056	0.12±0.014	0.13±0.041	0.16±0.053	0.15±0.070
o,p'-DDE	ND	ND	ND	ND	ND
p,p'-DDE	9.6±4.1	10.3±3.05	10.1±2.36	8.8±3.2	9.8±4.8
o,p'-DDD	ND	ND	ND	ND	ND
p,p'-DDD	0.19±0.19	0.055±0.015	0.073±0.057	0.068±0.0096	0.063±0.030
o,p'-DDT	ND	ND	ND	ND	ND
p,p'-DDT	0.064±0.050	0.018±0.017	0.010±0.010	0.010±0.0071	0.019±0.010
Total DDTs [2]	9.8±4.3	10.4±3.06	10.2±2.40	8.9±3.2	9.8±4.8
Total PCBs	43.0±18.6	77.3±26.3	84.8±22.9	62.5±20.4	68.3±15.8
Dieldrin	0.37±0.19	0.23±0.050	0.26±0.088	0.24±0.10	0.36±0.27
Toxaphene	0.25±0.25	ND	ND	ND	0.094±0.14
Endrin	ND [3]	ND	ND	ND	ND
Mirex	0.023±0.0071	0.068±0.059	0.057±0.029	0.035±0.017	0.028±0.0096
Weight (g)	2101±164.8	2137±112.0	2158±152.5	1895±77.7	1930±101.0
% Moisture	64.9±3.8	70.1±1.8	62.1±16.1	69.1±0.6	68.4±2.1
% Lipid	11.5±4.7	4.8±0.4	1.0±2.6	6.6±1.4	6.6±3.4

[1] Mean ± s.d.
[2] Total DDTs calculated from detectable DDTs only i.e. p,p'-DDE, p,p'-DDD, and p,p'-DDT.
[3] Endrin residues (0.03) ppm were above detection limit of 0.01 ppm in one sample.

Table 17. Chemical concentrations (ppm, wet-weight) in gut contents of double-crested cormorants collected from Cat Island, Green Bay during 1988.

	Cat Island (*n* = 3)
alpha-BHC	ND
beta-BHC	ND
delta-BHC	ND
gamma-BHC	ND
Oxychlordane	ND
alpha-chlordane	ND
gamma-chlordane	ND
trans-nonachlor	0.040±0.026
cis-nonachlor	ND
Heptachlor epoxide	ND
o,p'-DDE	ND
p,p'-DDE	0.20±0.045 [1]
o,p'-DDD	ND
p,p'-DDD	0.037±0.020
o,p'-DDT	ND
p,p'-DDT	ND
Total DDTs	0.25±0.060
Total Cl2 BIPH	ND
Total Cl3 BIPH	0.072±0.041
Total Cl4 BIPH	1.8±1.2
Total Cl5 BIPH	1.1±0.071
Total Cl6 BIPH	0.25±0.046
Total Cl7 BIPH	0.062±0.044
Total Cl8 BIPH	ND
Total Cl9 BIPH	ND
Total Cl10 BIPH	ND
Total PCBs	3.3±1.3
Dieldrin	0.033±0.014
Toxaphene	ND
Endrin	ND
Mirex	ND
Weight (g)	329.3±281.9
% Moisture	72.2±2.1
% Lipid	1.8±0.3

[1] Mean ± s.d.

Table 18. Chemical concentrations (ppm, wet- and lipid-weight) in carcasses and livers of adult male double-crested cormorants collected from Cat Island, Green Bay during 1988. [1]

	Wet Weight			Lipid Weight		
	Carcass (n = 8)	Liver (n = 8)	Liver to carcass ratio	Carcass (n = 8)	Liver (n = 8)	Liver to carcass ratio
HCB	0.026±0.014 [2]	0.014±0.0052	0.58±0.27	0.39±0.15	0.34±0.12	0.95±0.35
beta-BHC	0.023±0.013	0.014±0.010	0.60±0.21	0.37±0.25	0.34±0.24	0.99±0.29
Oxychlordane	0.13±0.055	0.054±0.023	0.44±0.16	2.0±0.84	1.3±0.48	0.69±0.080
alpha-chlordane	0.048±0.032	0.019±0.015	0.43±0.18	0.75±0.62	0.46±0.36	0.70±0.21
trans-nonachlor	0.041±0.024	0.016±0.0092	0.44±0.15	0.63±0.38	0.40±0.21	0.68±0.13
cis-nonachlor	0.11±0.048	0.036±0.015	0.38±0.18	1.6±0.60	0.89±0.34	0.57±0.093
Heptachlor epoxide	0.15±0.056	0.071±0.025	0.50±0.16	2.3±0.71	1.7±0.47	0.78±0.063
p,p'-DDE	9.4±3.8	3.9±2.3	0.41±0.15	144.6±66.9	95.1±52.3	0.65±0.11
p,p'-DDD	0.086±0.079	0.033±0.037	0.37±0.16	1.4±1.6	0.83±0.94	0.59±0.17
Total PCBs	64.8±17.1	24.7 ±10.4	0.41±0.17	1025±414.5	587.3±188.9	0.64±0.16
Dieldrin	0.37±0.25	0.21±0.097	0.72±0.40	5.1±2.3	5.1±2.3	1.07±0.33
Mirex	0.034±0.017	0.017±0.011	0.52±0.26	0.53±0.31	0.41±0.27	0.78±0.16

1) Sample included four "laying" males and four "incubating" males.

2) Mean ± s.d.

Table 19. Chemical concentrations (ppm, lipid-weight) in carcasses and yolk/whole eggs of laying double-crested cormorants collected from Cat Island, Green Bay during 1988.

	Lipid Weight		
	Carcass (n = 5)	Yolk/Whole egg (n = 5)	Correlation r
HCB	0.40±0.19 [1]	0.34±0.16	0.91
alpha-BHC	0.12±0.058	0.12±0.043	0.86
beta-BHC	0.32±0.23	0.17±0.15	0.96
gamma-BHC	0.11±0.053	0.075±0.024	0.55
Oxychlordane	2.1±0.67	1.6±0.55	0.99
alpha-chlordane	0.49±0.24	0.35±0.13	0.19
trans-nonachlor	0.43±0.24	0.29±0.14	0.86
cis-nonachlor	1.3±0.38	0.92±0.38	0.96
Heptachlor epoxide	2.2±0.74	1.6±0.55	0.93
p,p'-DDE	128±54.5	62.8±16.0	0.74
p,p'-DDD	1.0±0.11	0.69±0.14	0.07
p,p'-DDT	0.14±0.063	0.41±0.081	-0.14
Total PCBs	899±416.7	661±291.6	0.87
Dieldrin	3.3±1.3	4.2±2.1	0.62
Mirex	0.49±0.15	0.38±0.12	0.97

[1] Mean ± s.d.

Table 20. Chemical concentrations (ppm, wet-weight) in double-crested cormorants eggs collected from individual nests on Spider Island, Lake Michigan during 1988.

	Clutch 1 (n = 5)	Clutch 2 (n = 3)	Clutch 3 (n = 3)	Clutch 4 (n = 4)	Clutch 5 (n = 4)	Clutch 6 (n = 4)	Clutch 7 (n = 4)	Clutch 8 (n = 4) [1]
HCB	0.02±0.00 [2]	0.01±0.00	0.01±0.00	0.02±0.01	0.01±0.00	0.02±0.00	0.01±0.00	0.01±0.00
alpha-BHC	ND	ND	ND	ND	ND	ND	ND	ND
beta-BHC	ND	ND	ND	ND	ND	ND	ND	ND
delta-BHC	ND	ND	ND	ND	ND	ND	ND	ND
gamma-BHC	ND	ND	ND	ND	ND	ND	ND	ND
Oxychlordane	0.12±0.03	0.09±0.01	0.08±0.01	0.10±0.00	0.06±0.01	0.08±0.01	0.05±0.02	0.04±0.00
alpha-chlordane	0.02±0.01	0.02±0.00	0.02±0.01	0.03±0.00	0.01±0.00	0.03±0.01	0.03±0.01	0.01±0.00
gamma-chlordane	ND	ND	ND	ND	ND	ND	ND	ND
trans-nonachlor	0.02±0.01	0.02±0.00	0.02±0.01	0.03±0.00	0.01±0.00	0.03±0.00	0.03±0.01	0.02±0.01
cis-nonachlor	0.06±0.02	0.09±0.01	0.04±0.01	0.10±0.00	0.04±0.01	0.08±0.01	0.05±0.02	0.04±0.01
Heptachlor epoxide	0.11±0.03	0.12±0.01	0.07±0.01	0.13±0.00	0.06±0.01	0.11±0.02	0.07±0.02	0.05±0.01
o,p'-DDE	ND	ND	ND	ND	ND	ND	ND	ND
p,p'-DDE	3.44±0.59	3.82±0.17	2.40±0.20	5.21±0.07	1.95±0.26	3.73±0.39	2.35±0.37	1.00±0.12
o,p'-DDD	ND	ND	ND	ND	ND	ND	ND	ND
p,p'-DDD	0.03±0.01	0.02±0.00	0.03±0.01	0.04±0.00	0.02±0.00	0.04±0.00	0.04±0.01	0.02±0.00
o,p'-DDT	ND	ND	ND	ND	ND	ND	ND	ND
p,p'-DDT	0.05±0.02	0.02±0.01	0.04±0.01	0.04±0.00	0.03±0.01	0.04±0.01	0.04±0.02	0.02±0.01
Total DDTs [3]	3.52±0.61	3.86±1.80	2.47±0.22	5.29±0.07	1.99±0.26	3.80±0.39	2.43±0.40	1.04±0.12
Total PCBs	20.6±6.7	17.7±1.9	10.2±1.0	33.3±0.9	14.4±2.0	14.4±2.6	6.5±2.1	4.0±0.4
Dieldrin	0.24±0.07	0.41±0.05	0.18±0.03	0.42±0.01	0.17±0.02	0.47±0.06	0.27±0.10	0.12±0.02
Toxaphene	0.65±0.26	0.27±0.15	0.31±0.11	0.62±0.10	0.20±0.09	0.41±0.10	0.28±0.17	0.06±0.08
Endrin	ND	ND	ND	ND	ND	ND	ND	ND
Mirex	0.02±0.00	0.02±0.00	0.02±0.00	0.03±0.02	0.01±0.00	0.09±0.01	0.02±0.01	0.01±0.00
Weight±g	37.6±2.1	38.6±0.3	45.4±0.6	39.8±2.2	42.6±0.8	42.2±0.8	38.6±1.5	37.1±1.2
% Moisture	83.7±1.0	83.8±0.6	84.3±0.6	83.4±0.5	84.9±1.0	84.4±1.3	83.6±1.2	83.5±0.0
% Lipid	4.9±0.9	4.8±0.8	3.8±0.7	4.6±0.3	3.6±0.5	5.1±0.2	4.0±0.5	5.1±0.5

[1] One sample in clutch 8 was not corrected for moisture loss.
[2] Mean ± s.d.
[3] Total DDTs calculated from detectable DDTs only (p,p'-DDE, p,p'-DDD, and p,p'-DDT).

Table 21. Estimated variance components for 8 whole clutches of cormorant eggs.

Chemical	% variation: Between clutches	Within clutches
HCB	29.2	70.8
Oxychlordane	74.4	25.6
alpha-chlordane	41.9	58.1
trans-nonachlor	44.6	55.3
cis-nonachlor	78.8	21.2
Heptachlor epoxide	77.7	22.3
p,p'-DDE	93.7	6.3
p,p'-DDD	65.3	34.7
p,p'-DDT	29.4	70.6
Total DDTs	93.4	6.6
Total PCB	89.0	11.0
Dieldrin	84.1	15.9
Toxaphene	62.7	37.3
Mirex	88.9	11.1

Appendix I. Estimated detection limits (ppm, dry-weight) for metals in analyses of soil/guano, avian eggs, and avian carcasses collected from islands in Green Bay and Lake Michigan during 1987.

Metal	Soil	Eggs	Carcasses
Aluminum	3.0	0.3	0.3
Arsenic	0.1	0.1	0.1
Barium	0.1		
Beryllium	0.1	0.01	0.01
Boron	2.0		
Cadmium	0.2	0.03	0.03
Chromium	1.0	0.1	0.1
Copper	0.2	0.2	0.02
Iron	1.0	0.1	0.1
Lead	4.0	0.4	0.5
Magnesium	3.0		
Manganese	0.2	0.02	0.02
Mercury	0.004	0.004	0.004
Molybdenum	1.0		
Nickel	2.0	0.2	0.2
Selenium	5.0		
Silver	2.0		
Strontium	0.1		
Thallium	4.0	0.5	0.5
Vanadium	0.3		
Zinc	0.5	0.02	0.03